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CONDUCTIVE COLOR FILTERS

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CONDUCTIVE COLOR FILTERS

FIELD OF THE INVENTION

The present invention relates to conductive color filters and more particularly to conductive color filters useful in color display devices such as organic light emitting diode (OLED) displays.

BACKGROUND OF THE INVENTION

Organic light emitting diode (OLED) display devices utilize a current passed through thin film layers of organic materials to generate light. Electrodes located on either side of the organic layers provide current to the organic layers. The color of the light depends on the specific organic material and the light is emitted in every direction. A portion of the light is emitted directly toward the front of the display device: through a substrate (for a bottom emitter device) or a protective cover (for a top emitter device). A similar portion of the light is emitted toward the back of the display device and may be either absorbed or reflected by a layer behind the organic layers. OLED display devices can use emitters of different colors (for example, red, green, and blue) to form a full color display or can use color filters, either with the different colored emitters (as trimming filters), or with a single broad spectrum light emitter (for example, white) to form a full color display. The use of a white emitter with color filters to form a full color display is well known in the display industry and is practiced for liquid crystal displays and has been suggested for use with OLED displays.

The individual light emitting elements of a flat panel display are controlled by electrodes located on either side of a light emitting layer (e.g. an OLED) or a light modulating layer (e.g. an LCD). For example, OLED devices utilize a stack of organic layers (for example, hole injection, hole transport, emissive, electron transport, and electron injection layers) that, when current is passed through the layers, emit light whose frequency depends on the composition and structure of the layers and any intervening color filters. Alternatively, liquid crystal display light modulators controlled by electrodes and color filters to

provide a color display. In either case, light travels through one or more of the electrodes. Hence, there is a need for transparent electrodes for flat panel displays of these types.

Transparent electrodes are known in the prior art and typically include indium tin oxide (ITO) or thin layers of various types of metals or metal alloys. These electrodes have a limited transparency and conductivity and there is a recognized need for transparent conductors having improved transparency and conductivity. One technology proposed for providing transparent conductors are carbon nanotubes arranged in a thin layer. For example, WO2002076724 A1 entitled "Coatings Containing Carbon Nanotubes" published 20021003 discloses electrically conductive films containing nanotubes. The disclosed films demonstrate excellent conductivity and transparency. Methods of preparing and using the films are disclosed.

US 6,436,591 issued Aug. 20, 2002 to Ohtsu et al. shows a method of making a conductive color filter for an LCD display using a photoconductor and an electro deposition technique. The technique is complex and therefore expensive to implement.

There is a need therefore for an improved conductive color filter and method of making it.

SUMMARY OF THE INVENTION

The need is met by providing a conductive color filter that includes a layer of carbon nanotubes covered by a colored polymeric resin binder.

ADVANTAGES

The present invention has the advantage of providing an improved conductive color filter and manufacturing process.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic cross sectional view of a conductive color filter according to the present invention;

Fig. 2 is a schematic cross sectional view of a bottom emitting OLED display according to one embodiment of the present invention;

Fig. 3 is a schematic cross sectional view of a top emitting OLED display according to an alternative embodiment of the present invention;

Fig. 4 is a more detailed schematic cross sectional view of the top emitting OLED display as shown in Fig. 3;

Fig. 5 is a schematic cross sectional view of a top emitting OLED display according to an alternative embodiment of the present invention;

Fig. 6 is a schematic cross sectional view of a top emitting OLED display having multiple conductive color filters according to an alternative embodiment of the present invention;

Fig. 7 is a schematic cross sectional view of a bottom emitting OLED display having multiple conductive color filters according to an alternative embodiment of the present invention;

Fig. 8 is a schematic cross sectional view of a transmissive LCD display according to an alternative embodiment of the present invention; and

Fig. 9 is a schematic cross sectional view of a reflective LCD display according to an alternative embodiment of the present invention.

It will be understood that the figures are not to scale since the individual layers are too thin and the thickness differences of various layers too great to permit depiction to scale.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Fig. 1, the present invention is directed to a conductive color filter **10** formed on a substrate **12**. The conductive color filter includes a layer of carbon nanotube conductors **14** covered by a colored polymeric resin binder **16** to hold the nanotube conductors **14** in place and to protect them. The polymeric resin binder may be colored using a pigment or dye to provide light absorbing or transparent color properties to the polymeric resin **16**. The colors can be, for example, red, green, blue, or black. Carbon black may be used to provide a black colorant that will absorb all colors of light.

The construction of nanotubes, their deposition and the use of polymeric resins to provide structural stability are all known in the art. See, for example, WO2002076724 A1 cited above. Colored polymeric resins or polymers having dyes or pigments are also known and used to create conventional color filters, typically through photolithographic processes.

Conductive color filters may be applied in a variety of ways to improve the performance of flat panel displays. For example, referring to Fig. 2, a bottom emitter flat panel display has a substrate **12** with several conductive color filters $\mathbf{10_K}$, $\mathbf{10_R}$, $\mathbf{10_G}$, and $\mathbf{10_B}$ deposited upon it that absorb light or filters it to produce red, green, and blue respectively. The conductive color filters $\mathbf{10_R}$, $\mathbf{10_G}$, and $\mathbf{10_B}$ are individually addressable to form pixels. The black conductive color filter $\mathbf{10_K}$ absorbs ambient light to improve the contrast of the display, while conducting electricity to circuitry **26** located above the black conductive color filter $\mathbf{10_K}$ (for example conductors, transistors, and capacitors) that do not emit light. The black conductive color filter $\mathbf{10_K}$ absorbs ambient light, thereby improving the contrast of the display and forming a black matrix. Emissive materials **18**, for example, white light emitting OLED materials comprising a plurality of layers such as hole and/or electron injection layers and hole and/or electron transport layers, are deposited above the conductive color filters $\mathbf{10_R}$, $\mathbf{10_G}$, and $\mathbf{10_B}$ and may be coated in a single layer over the entire display area of the device.

The conductive color filters $\mathbf{10_R}$, $\mathbf{10_G}$, and $\mathbf{10_B}$ provide power to the emissive materials **18**. Another electrode **20** provides a second connection to conduct current from the conductive color filters $\mathbf{10_R}$, $\mathbf{10_G}$, and $\mathbf{10_B}$ through the emissive materials **18**. The electrode **20** may be reflective so that any light emitted from the emissive materials **18** toward the electrode may be reflected back through the substrate, as is conventionally done for bottom emitting emissive flat panel displays. The electrode **20** may also be colored to complement the conductive color filters $\mathbf{10_R}$, $\mathbf{10_G}$, and $\mathbf{10_B}$ and is electrically connected in common with all of the light emissive elements making up the display. Note that the use of

a black conductive color filter **10_K** may be independent of the conductive color filters **10_R**, **10_G**, and **10_B**.

Referring to Fig. 3, a top emitting embodiment of the present invention has a substrate **12** with several conventional electrodes **22** deposited upon it and located adjacent to the circuitry **26**. The conventional electrodes **22** provide power to the light emissive layer **18** and are individually addressable to form pixels. These conventional electrodes **22** may be reflective and colored to complement the conductive color filters **10_R**, **10_G**, and **10_B**. Electrode **24** provides power to the circuitry **26**. These electrodes and circuitry are conventional and known in the prior art. The light emissive layer may be coated in a single layer over the entire device. Above the light emissive layer **18** are located conductive color filters **10_K**, **10_R**, **10_G**, and **10_B**. The conductive color filters **10_K**, **10_R**, **10_G**, and **10_B** may be electrically connected in common (as was electrode **20** in Fig. 2) but have individually colored elements, e.g. red, green, and blue, associated with the electrodes **22**. Note that the conductive nanotubes may be deposited in a single coating over the surface of the display while differently colored polymeric resins are deposited in either one or multiple steps, for example with an inkjet device. The layer of polymeric resins can also function as a protective layer in a top emitting OLED device.

This top emitting arrangement is shown in more detail in Fig. 4. Referring to Fig. 4, the electrodes **22** pass through vias in electrode **24** and circuitry **26** and are coated over the circuitry **26** to provide a greater emissive area in the same surface area. The emissive materials **18** are coated in layers over the entire display area of the device, including the circuitry **26**. The black conductive color filter **10_K** and color filters **10_R**, **10_G**, and **10_B** are deposited as described above to form the second electrode.

Referring to Fig. 5, a top emitting embodiment of the present invention using the conductive color filter arrangement of Fig. 2 has conductive color filters **10_R**, **10_G**, and **10_B** located over the circuitry **26** and has black filter **16_K** located between them to provide additional contrast. These layers are

deposited prior to the emissive materials **18** and after the construction and patterning of any circuitry **26**.

Note that the arrangements of conductive color filters **10** shown in Figs. 2-5 are not mutually exclusive. For example, conductive color filters **10** having a common color can be located on both sides of the emissive materials **18**. An additional, reflective layer may be added to the conductive color filters e.g. **22** or **20** in the direction opposite the desired direction of emission to redirect light in a desired direction. Thus, any light that is emitted away from the desired direction of emission may pass through a conductive color filter, be reflected, pass through the conductive color filter a second time, pass through the emissive material **18**, and then pass through the other conductive color filter and be emitted from the display. Passing through multiple filters can improve the color purity of the light emitted. Fig. 6 illustrates this embodiment for a top emitting display, and Fig. 7 illustrates this embodiment for a bottom emitting display.

The additional reflective layer may also be conductive and may enhance the overall conductivity of the conductive color filter **10**. In addition, a transparent, conductive electrode may be deposited upon or beneath the conductive color filter **10** to enhance the overall conductivity of the conductive color filter **10**. The additional reflective or transparent conductive electrode may also serve to protect underlying layers or provide improved materials compatibility between the layers.

The conductive color filters **10** are typically deposited in two steps. The first step is the coating of a dispersion of carbon nanotubes **14** in a carrier fluid. The carrier fluid is dried after which a colored polymeric resin binder **16** is applied in a thin layer over the carbon nanotubes. The polymeric resin material can comprise a wide variety of natural or synthetic polymeric resins, including but not limited to thermoplastics, thermosetting polymers, elastomers, and combinations thereof. Additional examples include polycarbonate and polyethylene teraphthalate. The polymeric resins can include a wide variety of additives in addition to the colorants such as pigments or dyes described above to provide a variety of benefits. For example, desiccant material can be used to

provide resistance to humidity and ultra violet light absorbers can be added to protect the underlying materials from UV exposure.

The colored polymeric resin binder **16** can be deposited at a variety of thicknesses. In one embodiment, the polymeric resin binder is deposited in a very thin layer so that the conductive color filter **10** is conductive through the thickness of the film. This structure is necessary for the embodiment shown in Fig. 5. To achieve this conductivity, it may be necessary to repeat the film deposition process of depositing carbon nanotubes and polymeric binder successively until the conductive color filter **10** has achieved the necessary thickness to provide the desired light filtering capability and electrical conductivity.

Alternatively, it may be desirable for the conductive color filter **10** to conduct from only one side of the film, for example in the embodiment shown in Fig. 4. In this arrangement, an initial layer or layers of conductive nanotubes **14**, with or without impregnating polymeric resin **16** may be deposited followed by a thicker layer of polymeric resin binder. The thicker layer of polymeric resin binder may be deposited in one step or in multiple, repeated steps. The thickness of the polymeric resin binder layer may be such that the conductive nanotubes are completely covered. In this way, very thick color filters can be created in fewer steps, but the resulting color filters are conductive only from one side of the layer.

It is also possible to first deposit a thick polymeric resin layer and then coat successive layer(s) of conductive nanotubes **14** so that the conductive color filter **10** is conductive on the side of the film having the final deposition layers rather than the first deposition layers. In this case, the initial coating(s) of polymeric resin acts as an insulator on which the conductive color filter is deposited. The initial coating may include the color filtering agents and any other desired additives.

The deposition of polymeric resin binder **16** as part of the process for forming the conductive color filters **10** can also serve to provide a black matrix for the display device. In this case, the conductive nanotubes are deposited only in the areas where an electrode is desired. However, the polymeric resin is

deposited more broadly over the surface of the device. Where the conductive nanotubes are located, a conductive color filter will be formed. Where no conductive nanotubes are located, a non-conductive color filter will be formed. In this way, components of the conductive color filter and a non-conductive color filter may be formed in common processing steps. For example, the embodiment shown in Fig. 5 requires that the element **16_K** be non-conductive and light absorbing. In Figs. 3 and 4 it may not be required but may be preferred that the elements **10_K** be conductive to improve the overall conductivity of the common electrode **20**. In Figs. 3 and 4 it is only necessary that the conductive color filter be conductive on the side contacting the emissive materials **18**. In Fig. 2, portions of the conductive color filter **10_K** contacting the circuitry **26** may be conductive (as shown). Alternatively, portions of the conductive color filter **10_K** may not be conductive and will only comprise insulative resin.

As applied to top emitting OLED flat panel displays, the present invention provides an efficient and low cost means for creating a conductive color filter array by depositing an unpatterned layer of carbon nanotubes over a white light emissive layer on the display. Patterned colored polymeric resin binders can then be efficiently deposited over the carbon nanotubes using an ink jet device to form an array of electrically connected conductive color filters.

The present invention can be applied to both flat panel displays having emissive materials located between electrodes as shown in Figs. 2-7 and liquid crystal displays, such as a backlit or reflective LCDs.

Fig. 8 illustrates a backlit embodiment of the present invention with an emissive source **18** emitting light through conductive color filters **10_R**, **10_G**, and **10_B** then through a liquid crystal layer **30** and then through a second electrode **20**. Conductive color filters may be used in the place of electrode **20** and black conductive color filters or black filters may be used in conjunction with circuitry **26** (not shown) as described above.

Referring to Fig. 9, a reflective embodiment of the present invention uses a similar arrangement of conductive color filters, with the addition of a reflective layer **32** at the back of the device. In this arrangement, light passes

first through the electrode **20** (or conductive color filters, not shown), then through the liquid crystal layer **30**, through the second conductive color filters, is reflected from the reflective layer **32**, passes through the conductive color filters, liquid crystal layer **30**, and electrode **20** again. (In Figs. 8 and 9 additional polarizers, diffusers and other layers necessary to a construct a complete liquid crystal display are not shown.)

The present invention can be employed in most OLED device configurations that employ a white light emitting element in each pixel. These include simple structures comprising a separate anode and cathode per OLED and more complex structures, such as passive matrix displays having orthogonal arrays of anodes and cathodes to form pixels, and active matrix displays where each pixel is controlled independently, for example, with a thin film transistor (TFT). As is well known in the art, OLED devices and light emitting layers include multiple organic layers, including hole and electron transporting and injecting layers, and emissive layers. Such configurations are included within this invention.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

10	conductive color filter
10_K, 10_R, 10_G, 10_B	differently colored conductive color filter
12	substrate
14	nanotube conductors
16	polymeric resin binder
16_K	black color filter
18	emissive materials
20	electrode
22	electrode
24	electrode
26	circuitry
30	liquid crystal layer
32	reflective layer